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Field measurement to assess the correlation between wind ventilation performance of and wind structure inside a street with an elevated structure in Bangkok, Thailand

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Abstract

To reduce the health risk to pedestrians, urban ventilation has becomes increasingly important to reduce the concentrations of car exhaust emissions. In this study, the ventilation performance of a street in Bangkok, Thailand, was investigated by performing measurements therein. As a result, the influence of elevated structures was shown. It was also observed that the density of exhaust gas is a simple function of the wind speed and traffic volume when the wind is blowing parallel to the street. However, the ventilation efficiency varied drastically depending on the angle between the street and the wind direction when the wind direction was not stable.

Urban Ventilation; Field measurement; Bangkok; Thailand; NO_2; Elevated sturucture

1. Introduction

In order to reduce the density of toxic gases in the urban atmosphere thereby reduce the health risks due to air pollution, one option is to limit the generation of toxic gases. Another option is to dilute the generated gas by mixing the urban air with fresh air from higher altitudes. The ultimate objective of this study is to optimize the mechanism of dilution of toxic gases in residential areas and enhance the urban ventilation efficiency. For this purpose, the influence of various factors on urban ventilation is studied first. In particular, this study aims to optimize the ventilation performance of streets in Asian cities, where air pollution due to automobile emissions is still of grave concern.

In Bangkok, Thailand, the government has been taking strong measures to reduce air pollution, such as the

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adoption of unleaded gasoline and the expansion of mass transport systems such as the subway and BTS SkyTrain (hereafter BTS). These measures have been proven to be effective to a certain degree. However, traffic jams in urban areas still remains a major problem, and air pollution from automobile emissions is still a health risk to citizens [1]. Insufficient urban infrastructure in comparison to the rapidly growing urban population is considered the major reason for these problems. For a variety of historical reasons, Bangkok still maintains its ancient urban structures. In the old days, waterways were the major routes for traffic, and therefore, Bangkok's percentage of road surface area is extremely low as compared to other major cities of the world (Table 1). The low road surface area and the increase in the urban population are the major reasons for the lack of improvement in the traffic of Bangkok, despite the expansion of the public transportation system.

Table 1: Percentage of road surface area of major cities [2]

City	Percentage of road surface area (against total area of the city) [%]
Tokyo	14.8
London	16.6
Paris	20.0
New York	23.2
Washington D.C.	25.0
Bangkok	8.1

2. Measurement Method

2.1. Subjects of Measurement

The concentrations of exhaust gas were measured on "Rama I Street" in Bangkok, which is partially covered by the BTS railway and passes the BTS National Stadium Station. The street has two lanes north of the center divider and three lanes on the south. Traffic jams are observed during the day. In order to determine the effects of elevated structures, measurements were performed at three different locations: (1) at a point having no elevated structures, (2) at a point where the BTS railway covers only the center divider, and (3) at a point where there is a BTS station and all lanes are covered by an elevated structure. Air samples for concentration measurements were collected at the center divider. Figure 1 shows the measurement locations, along with photographs of each location. In order to limit the influence of traffic volume change, each of the three locations was chosen at specific intervals on the same street such that there were no major intersections.

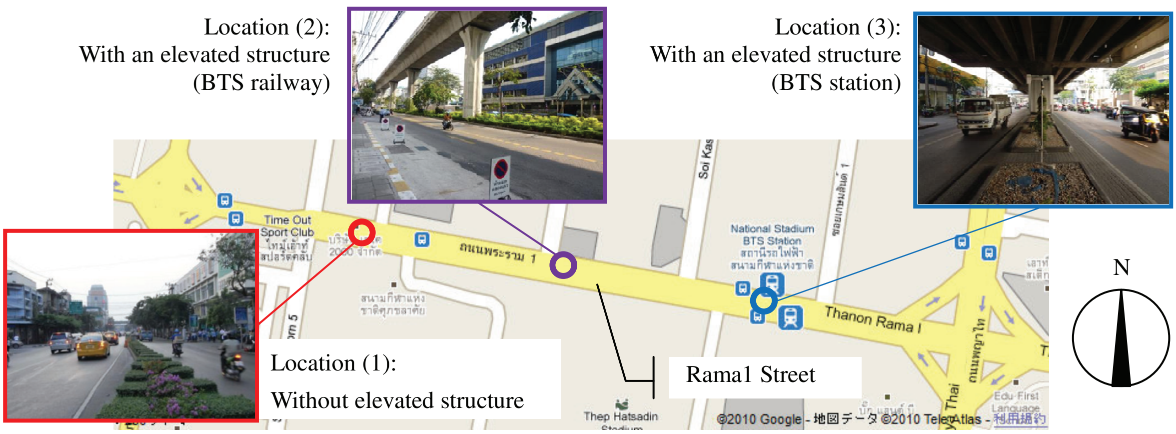

Figure 1: Description of measurement locations

2.2. *Description of Measurements*

The concentration of exhaust gas is represented by the concentration of NO_2, which has a strong correlation with traffic volume. At each measurement location, a sample of 10 l of air was collected in a Tedlar® bag for 10 min (to determine the 10-minute average concentration) at the center divider. Samples were collected at a height of approximately 160 cm to approximate the location of breathing while standing upright. The concentration of NO_2 was determined with a detector tube (Kitagawa gas detector tube 740, supplied by Komyo Rikagaku Kogyo, measurement range for NO_2: 0.01 to 0.2 ppm). The concentration of sulfur dioxide, which hinders NO_2 measurement, was recorded with a detector tube for sulfur dioxide and was confirmed to be low enough not to adversely affect NO_2 measurement during each measurement. Traffic volume was determined by making a video recording at location (3). The traffic volume at location (1) and location (2) are assumed to be the same as at location (3) as there are no major intersections between the locations. The measurements took place on January 27th and 28th, 2010, and were taken five times each day at 6:00, 8:00, 12:00, 16:00, and 18:00. As for location (2), however, measurements were taken only on January 27th, 2010. In addition, wind direction, wind speed, temperature, humidity, and solar radiation were measured approximately 1 km south of the street locations at the meteorological observation station at Chulalongkorn University. The meteorological observations were performed at five-minute intervals at a height of 18 m above ground.

3. Results

Figure 2 shows wind direction and wind speed on January 27, 2010. For this wind direction, an angle of zero degrees represents a northerly wind. The wind was blowing from the northwest until about 7:00 when it shifted to a constant easterly wind. As Rama I street runs east-west, the day was characterized by wind blowing parallel to the street. Figure 3 shows wind direction and wind speed on January 28, 2010. Unlike on the 27, wind direction was not constant throughout the day: the wind shifted from easterly, in the morning, to westerly, in the evening. Measured NO_2 concentrations, traffic volume, atmospheric temperature, humidity, and solar radiation are summarized in Table 2.

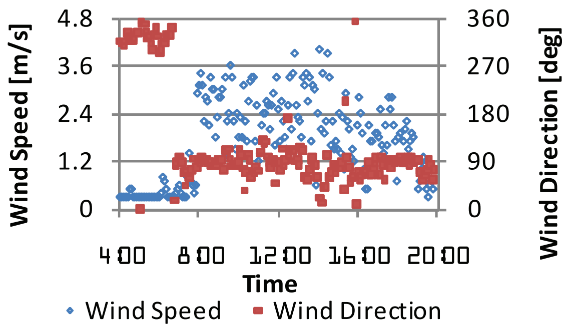

Figure 2: Wind direction and speed on January 27, 2010

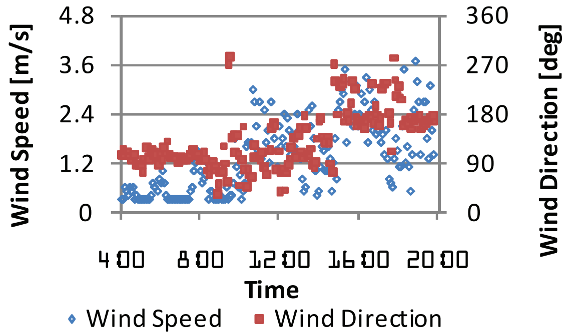

Figure 3: Wind direction and speed on January 28, 2010

Table 2: Measurement results

Time of measurement	NO_2 concentration [ppm]			Traffic [no. of vehicles /10 min]	Atmospheric temperature*1 [□]	Humidity*1 [%RH]	Solar radiation*1 [W/m^2]
	Location (1)	Location (2)	Location (3)				
Jan 27 6:20–6:30	0.062	0.064	0.078	405	26.6	66.3	18
8:00–8:10	0.072	0.068	0.096	726	28.3	54.1	134
12:00–12:10	0.096	0.096	0.152	825	32.7	43.4	267
16:00–16:10	0.124	0.124	0.164	864	32.6	44.9	269
18:00–18:10	0.136	0.104	0.152	649	31.4	44.6	24
Jan 28 6:00–6:10	0.064	n/a	0.064	324	26.5	65.9	20
8:00–8:10	0.092	n/a	0.092	836	27.3	68.5	131
12:00–12:10	>0.2 *2	n/a	>0.2 *2	760	33.0	45.3	151
16:00–16:10	>0.2 *2	n/a	>0.2 *2	721	33.2	50.1	291
18:00–18:10	0.160	n/a	0.144	679	30.8	54.3	24

*1 Mean value of the five-minute values from the start of measurement

*2 Above the upper limit of measurement range (0.2 ppm) of the detector tube

Figure 4 shows the relationship between traffic volume and NO_2 concentration on January 27, when the wind direction was stable. At 6:00, when there was little traffic, the concentration of NO_2 was relatively low. As the traffic volume increased after 8:00, the concentration tended to increase. The tendencies at location (1) and (2) were the same throughout the day which shows that the relatively small elevated structure which covers only the center divider does not influence the ventilating efficiency. On the other hand, the concentrations were higher at location (3) relative to the two other locations. This is an indication of a reduction in ventilating efficiency due to the elevated structures which cover the road area. The maximum concentration was found at location (3) at 16:00 with a value of 0.164 ppm; this value was slightly higher than the concentrations found at locations (1) and (2).

Figure 5 shows the relationship between the traffic volume and NO_2 concentration on January 28 (wind direction shifted throughout the day). The peak value exceeded 0.2 ppm, the upper limit of the measurement range of the detection tube, at 12:00 and 16:00 on January 28. This is above the level stipulated in the environmental guidelines of Thailand (maximum mean value for 1 h: 0.17 ppm [4]). The concentration at all three locations has similar values. Uehara et al. show that the lid effect from the elevated road does not significantly increase ground-level concentrations when the wind direction is perpendicular to the road [3]. Thus, the lid effect was not prominent on January 28.

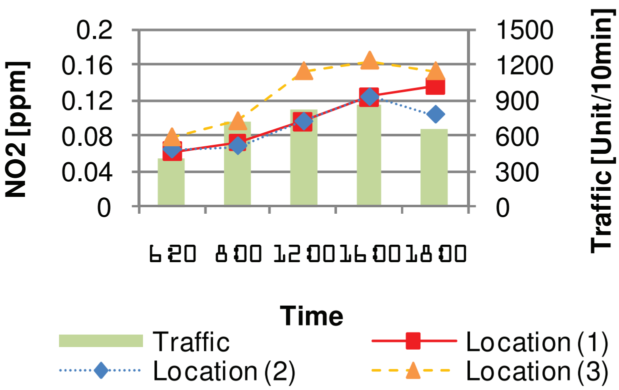

Figure 4: NO_2 concentration and traffic volume on January 27, 2010

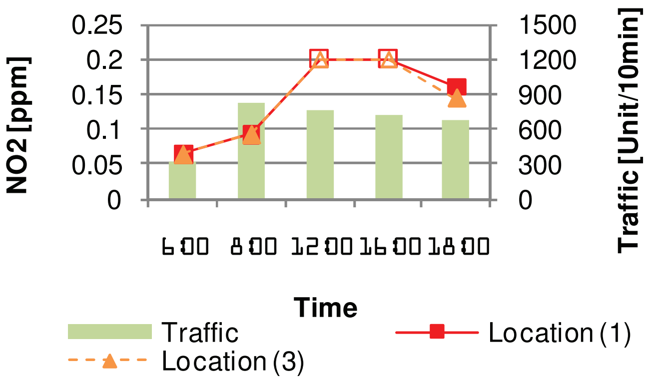

Figure 5: NO_2 concentration and traffic volume on January 28, 2010 (data at 12:00 and 16:00 are reference values)

4. Discussion

The NO_2 concentrations at location (1) at 12:00 and 16:00 on January 28 are approximately double the concentrations of January 27 (at the same time of day and location). Since there was more traffic on January 27, it is probable that the exceptionally high concentration observed on January 28, is due to the effects of wind, and not simply traffic volume. To verify this phenomenon, partial correlation coefficients were calculated between values of NO_2 concentration and both traffic volume and wind speed. Table 3 shows the results obtained for the data at or after 8:00 on January 27 and at 6:00 on January 28, 2010, when the wind was easterly. Table 4 shows the results obtained for all measured data.

Table 3 Partial correlation coefficients (data collected for easterly wind)

	Correlation function (Significance probability)	
	NO_2 concentration & traffic volume	NO_2 concentration & wind speed
Location(1)	0.88 (0.12)	-0.83 (0.17)
Location(3)	0.97 (0.04)	-0.90 (0.11)

Table 4 Partial correlation coefficients (all recorded data)

	Correlation function (Significance probability)	
	NO_2 concentration & traffic volume	NO_2 concentration & wind speed
Location(1)	0.35 (0.36)	0.00 (1.00)
Location(3)	0.42 (0.26)	0.19 (0.62)

From Table 3, it is observed that, under constant wind conditions, there is a strong positive correlation between NO_2 concentration and traffic volume and a strong negative correlation between NO_2 concentration and wind speed. Therefore, when the wind is constant, the concentration of exhaust gas near the road can be roughly estimated based on traffic volume and wind speed.

On the other hand, Table 4 indicates that there is almost no correlation between concentration of NO_2 and wind speed when the wind direction is not stable and a weak correlation exists between the NO_2 concentration and traffic volume. In other words, the effect of wind direction on the concentration of exhaust gas near the road is significant, and the necessity of considering urban ventilation, which depends on wind direction, is evident. Unlike the wind environment where it is parallel to the street, particularly, in cases where the wind blows perpendicular to the street, as observed on January 28, there is a possibility of a drastic increase in the exhaust gas concentration; this situation calls for immediate attention.

In addition, it must be noted that, even when the wind is favorable for the dilution of exhaust gas (for example the wind blowing parallel to the street as observed on January 27), there exists a possibility that high exhaust gas concentration may develop due to obstacles to ventilation, such as elevated structures.

5. Conclusions

In this study, the ventilation performance of a street in Bangkok, Thailand, was investigated by performing field measurements therein. Rapid economic growth and urbanization in Bangkok have caused serious air pollution due to automobile emissions, despite the expansion of public transportation systems, including subways. The results of this study show that various factors affect urban ventilation, especially elevated structures. It was also observed that the concentrations of exhaust gases can be explained simply in terms of the wind speed and traffic volume when the wind blows parallel to the street. However, the ventilation efficiency varies drastically with the angle between the wind direction and the direction of the street when the wind direction is not stable. In the future, further study and validation will be carried out by performing a numerical fluid analysis using the obtained data.

Acknowledgement

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